Initial Evaluation of Potential Human Health Risks Associated with Playing on Synthetic Turf Fields on Bainbridge Island

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Both the Bainbridge Island Metro Parks and Recreation District and the Bainbridge Island School District are considering the replacement of current playing field surfaces with synthetic turf fields. The field at Battle Point Park currently is an all weather sand matrix, while the field at the high school is natural grass. There has been considerable discussion about the potential human health and environmental risks posed by synthetic turf fields, especially those that incorporate tire crumb into the turf. Tire crumb is primarily produced from recycled tires and is increasingly used in a variety of ways in recreational environments including playing fields, playgrounds, and tracks. Tire crumb was used in the two Battle Point Park fields when they were installed more than 20 years ago.

I was asked to review the available scientific literature and publications in order to provide an assessment of the information contained in these materials about the potential risks to human health to children and teenagers that may play on these new fields and the risks to the environment that may result from precipitation runoff collected from the fields. This report focuses on the risks to human health. I was also asked to formulate an opinion regarding the potential risks posed by the use of synthetic turf fields on Bainbridge Island[1]. The following is an analysis of the potential human health risks to athletes related to potential exposure to chemicals that could be released from tire crumb used in the construction of these fields.

Chemical Composition and Potential Releases

A number of researchers have analyzed tire crumb to determine its chemical composition. In some of the analyses the tire crumb has been completely dissolved using strong acids and high temperatures in order to determine its chemical composition (See data published

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by Crain and Zhang [2006, 2007]; Plesser and Lund 2004). Plesser and Lund (2004) analyzed tire crumb used on turf fields and found detectable concentrations of 8 metals, PCBs, 16 individual PAHs[2], 8 phthalates, and 3 phenols in nearly all of the tire crumb samples. Although useful in cataloguing the chemical constituents that make-up tire crumb, these analyses do not provide information that can be directly applied to environmental issues since they do not take into account the leaching potential and bioavailability of the chemicals. Crain and Zhang acknowledged this issue, noting that: "We want to emphasize that the findings are preliminary. PAHs in rubber might not act the same way as in soil, and we do not yet have information on the ease with which PAHs in these rubber particles might be absorbed by children or adults – by ingestion, inhalation, or absorption through the skin." (Crain and Zhang 2006). "The next step is to study the bioavailability of PAHs…" (Crain and Zhang 2007). Bioavailability generally describes the way chemicals are absorbed by humans and other creatures.

Since the complete dissolution of a product may not provide data that helps understand the potential environmental exposure, other analytical procedures have been developed that mimic natural conditions to better capture the chemicals that might be released into the environment. Tests to analyze the potential for contaminants to separate from the tire crumb have been conducted in a number of ways. The potential for contaminants to be released into the environment during rain and other precipitation events has been assessed using a leachate sample. This involves mixing a known amount of tire crumb with water, letting it sit for a period of time, and then analyzing the water for chemicals that may have leached out of the tire crumb. In order to determine what chemicals might leach from tire crumb if it is ingested by humans, tire crumb has been placed in an acidic solution meant to mimic the digestive environment of the stomach. Additionally, tests have been performed to determine the extent to which chemicals may volatilize or off-gas from the tire crumb into the air.

The results of the various leachate tests discussed in the existing literature show that crumb tire has the potential to release some chemicals, although some study result differ both in the identity of the chemicals detected and in their concentrations. The concentration of chemicals that were released from the tire crumbs into the water, acidic solution, or air varied greatly, but was generally much lower than the concentration of chemicals present in the rubber granules themselves. Most studies report detected concentrations of a limited suite of chemicals that include metals, a number of organic compounds and PAHs. Some of the chemicals that have been detected in leachate are known or suspected carcinogens. A comprehensive study of tire crumb conducted by the State of California's, Office of Environmental Health Hazard Assessment (OEHHA) presents a relatively complete summary of chemicals found in crumb tire studies that was performed by other researchers (OEHHA 2007; see Table 1 of that document). Examples of the classes of chemicals found in tire crumb are shown in Table 1.

[2] PAHs is an abbreviation for a class of petroleum compounds collectively termed "polycyclic aromatic hydrocarbons".

Table 1. Chemical classes present in tire crumb leachate

Chemical Class	Example Chemicals	Other ways huamns may be Exposed
Metals	arsenic, cadmium, zinc, copper, lead, iron	varies by chemical, but may include consumption of contaminated foods, water contamination due to rusting pipes, automobile exhaust
Phthalates	Bis (2-ethylhexyl) phthalate	household cleaning products, plastics
Polyaromatic hydrocarbons (PAHs)	benzo(a)pyrene, pyrene	breathing air contaminated with smoke or exhaust, eating charred meats (e.g. hamburgers)
Polychlorinated biphenyls (PCBs)	various congeners and aroclors	consumption of contaminated food, electrical appliances
Volatile organic compounds (VOCs)	benzene, toluene	freshly paint, rubber-based floors, auto exhaust

Plesser and Lund (2004) conducted a series of mobility tests to determine the degree to which chemicals were leached from tire crumb. Their results for both metals and organic compounds indicate that only a very low percentage of the total concentration of the chemicals found in the tire crumb (usually less than 0.001 percent) leached out. The only exception was zinc, which showed mobility ranging from 0.01 percent to 0.31 percent across the four samples analyzed.

While the use of leachate tests are valuable in estimating what chemicals might be released into the environment under “natural conditions”, the preferred method is to actually measure chemicals at constructed synthetic turf fields. A joint study conducted by ALIAPUR (a French governmental agency responsible for regulating uses of used tires) and ADEME (the French Agency for Environment and Energy Management), installed a rain collection system that caught precipitation that had percolated through a synthetic turf field. The results of that study showed relatively low, but detectable concentrations of a number of organic compounds and metals. However, these concentrations were generally lower than the applicable drinking water standards (Moretto 2007). In another study conducted in Norway, measurements were made of volatile organic chemicals in the air at indoor facilities containing synthetic turf fields (NIPH 2006).

In summary, the results of the analytical work conducted to date indicate that the concentration of tire crumb and potential for release of chemicals is dependant on the technique used. The highest concentrations were detected when tire crumb was completely dissolved. However, complete dissolution will not occur under environmental conditions, thus leachate tests or site-specific analyses are more relevant.

Human Health Risks

Data on the chemical composition of crumb tire and the potential for chemicals to be released is important in understanding the potential health concerns for athletes that play on synthetic turf fields. All chemicals, other than radionuclides, exhibit a dose response relationship between the exposure concentration (dose) and level of effects (response). See Figure 1 for a general dose response curve. This means that the potential for effects increases as the dose increases. The dose response relationship forms the basis of the ability to quantitatively estimate risks associated with chemical exposures.

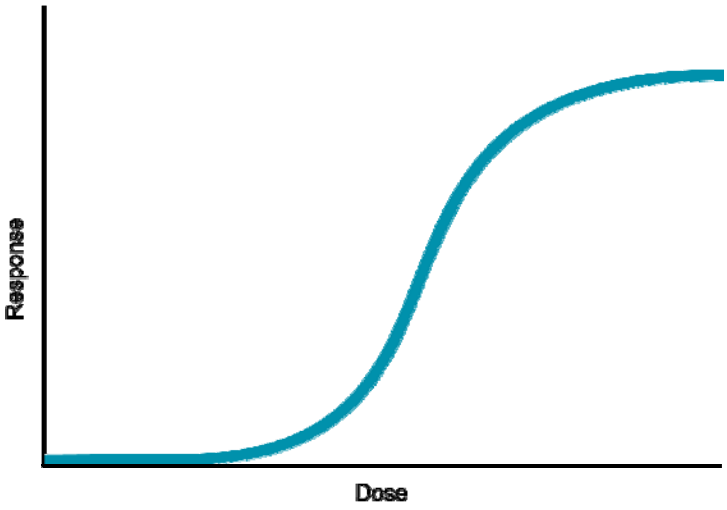

Figure 1. Example of a typical dose-response curve

To evaluate potential human health risks and make risk management decisions, standardized risk equations have been developed that are extensively used by North American and European by regulatory agencies. Risk equations require four types of information:

1. Concentration of the chemical to which a person will be exposed.
2. Route of exposure for the chemical. Routes of exposure include ingestion of the chemical, absorption of the chemical through the skin, and inhalation of the chemical attached to airborne particles and in the form of a vapor.
3. Duration of the exposure.
4. Toxicity or potency of the chemical.

Several organizations have used risk equations to determine if the use of tire crumb represents a risk to humans who may use playgrounds or playfields composed of this material. The State of California's Office of Environmental Health Hazard Assessment (OEHHA 2007) published an evaluation of risks to young children who ingest tire crumb while playing in areas with tire crumb used as ground cover. The analysis included 22 chemicals, including carcinogens, which were detected based on a gastric digestion extraction (i.e., where tire crumb was placed in an acidic solution as described above to simulate gastric digestion, and then the solution was analyzed for chemicals that may

have been released by the tire crumb). The analysis assumed a one-time ingestion of 10 grams of tire shreds[3]. For chemicals that are classified as carcinogens, OEHHA concluded that the cancer "…risk is considerably below the *de minimis* risk level of 1 x 10^{-6} (one in one million)[4] generally considered an acceptable cancer risk due to its small magnitude compared to overall cancer rate." For chemicals that are non-carcinogenic, the authors concluded: "…all exposures were at or below the screening values suggesting a low risk of non-cancer acute health effects."

In the report, OEHHA (2007) also estimated risks for 49 chemicals that have been reported in other studies. The analysis used the highest published concentrations released by the tire shreds and also assumed a one-time ingestion of 10 grams of tire shreds. For both cancer and non-cancer risks, OEHHA (2007) concluded that risks were considered below health effects levels, except for zinc. Exposure to the maximum concentration of zinc reported resulted in the exceedance of its health-based screening value[5]. Use of all other values reported in the literature would not have resulted in an exceedance of the screening value.

Another risk assessment was published by Moretto (2007) for ALIAPUR and ADEME in which he evaluated health risks linked to vapor emissions from synthetic turf fields were evaluated. The risk assessment focused on a set of chemicals including nine volatile organic compounds (VOCs) and formaldehydes. Among the exposure scenarios used was one for amateur athletes which assumed training 3 times a week for 2 hours and playing in competition for 4 hours. This level of activity was considered extreme by the authors, as they believed it overestimated the level of activity that would be undertaken by amateur athletes. All practices and competitions were assumed to be in indoor facilities, a condition the authors also considered to be a worst-case scenario for risk from inhalation of VOCs and formaldehydes. Based on their analysis the authors concluded: "…..the results of the HRE[6] show that that the VOC and aldehyde emissions identified…..present no cause for concern as regards human health in an indoor situation."

The Norwegian Institute of Public Health and the Radium Hospital (NIPH 2006) also investigated the risk to humans from playing on synthetic turf fields in indoor facilities. Their study included an assessment of risks from inhalation, skin contact and ingestion of tire crumb particles on adults, juniors and older children. The authors used worst case scenarios which they considered would clearly overestimate the health risk. Exposure

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[3] As noted by the authors concerning the use of a one-time exposure to estimate a lifetime exposure, "The assumption that the risk from a onetime exposure is equivalent to the risk from the same dose spread over a lifetime is uncertain, and may overestimate or underestimate the true risk."

[4] Risk assessments generally determine the excess cancer risk that may be associated with an individual participating in an individual activity for a given period of time. The interpretation for the above risk estimate is that there is a one in one million chance that cancer will arise in an individual if the described activity is undertaken.

[5] OEHHA noted that the range in zinc concentrations from the literature was large. The authors note: "Thus, using most zinc leaching values other than the maximum value in Table 9 would result in an estimated dose that was below the subchronic screening level for zinc. This underscores the importance of accurate leaching data."

[6] HRE = Health Risk Evaluation

duration ranged from 4 to 6 months and 4 to 7 sessions per week depending upon the age group (longer for adults than children). The results of their analysis indicated that playing on synthetic turf fields do not cause any increased health risk. They concluded: "Recycled rubber granulate contains many chemical substances which are potentially harmful to health. The concentrations of these substances are however extremely low, they are only leached from the rubber granulate in very small quantities….. On the basis of estimated exposure values and the doses/concentrations which can cause harmful effects in humans or in animal experiments, it is concluded that the use of artificial turf halls does not cause any elevated health risk. This applies to children, older children, juniors, and adults."

Bainbridge Island Sport Play Scenario

While the above risk assessments are useful, none of the exposure scenarios match up with the expected use on Bainbridge Island. Here the fields will be constructed outdoors and will principally be used by children and teenagers participating in team sports such as football, soccer, and lacrosse. For the purposes of analyzing the potential health risks that might be associated with playing on synthetic turf fields in the Pacific Northwest, Windward Environmental constructed an exposure scenario for both a child ("child sport play scenario") and a teenager ("teenager sport play scenario") that actively participates in team sport play on a turf field. The child sport play scenario assumes that a child uses the turf field for 3 years (from age 8 to 10), and plays for 3 hours/day for 261 days/year (year around play). The teenage sport play scenario assumes that a teenager uses the turf field for 7 years (from age 11 to 18), and plays for 3 hours/day for 261 days/year (year around play). Exposure pathways included absorption through the skin from contact with tire crumb leachate, inhalation of VOCs, and ingestion of whole tire crumb particles. Other exposure parameters used in the risk models are presented in Table 2.

Table 2. Summary of exposure parameters used to define exposure dose

Parameter Name	Units	Value		Rationale
		Child	Teenager	
Exposure duration	years	3	7	Child: approximately grades 3 to 5 (ages 8 to 10) Teenager: middle school and high school years, ages 11 to 18
Exposure frequency	days/yr	261	261	Conservative assumption of a 3-hour practice, 5 days per week throughout the year. Could be representative of elite players.
Exposure frequency	hrs/day	3	3	
Body weight	kg	30	50	Estimated based on values recommended by EPA
Exposed surface area	cm^2	3,000	5,100	Estimated based on values recommended by EPA
Inhalation volume	m^3/hr	1.9	3.2	Based on EPA breathing rate during high exertion
Dermal adherence factor	mg/cm^2	1	1	Highly conservative – assumes 100% adherence and absorption of chemicals through skin. This value is likely to be much lower.

Parameter Name	Units	Value		Rationale
		Child	Teenager	
Incidental ingestion rate	g/day	0.2	0.1	Assumes the consumption of 0.2 g/day of the rubber granules by children (EPA default value for soil ingestion). Because the consumption of the rubber granules is unlikely for all groups except very young children, the value used for teenagers is 0.1 g/day. These values are conservative, and assume the consumption of 73 g/year of rubber by children, and 36.5 g/year are by teenagers.

Chemicals used in the risk assessment are listed in Table 3 and 4 and include both carcinogens and non-carcinogens. Chemicals were selected based on availability of toxicological information, and are representative of all chemicals identified in tire crumb material to date. All concentrations used in the analysis were the highest measured concentrations listed in the following studies:

- Artificial turf pitches – an assessment of the health risks for football players (prepared by NIPH 2004)
- Potential health and environmental effects linked to artificial turf systems – final report (Plesser and Lund 2004)
- Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products (OHHEA 2007)

Table 3. Summary of excess cancer risks associated with playing on synthetic turf fields

Chemical	Excess Cancer Risks Across All Exposure Routes							
	Child				Teenager			
	Inhalation	Dermal Adherence	Incidental Ingestion	Total	Inhalation	Dermal Adherence	Incidental Ingestion	Total
Acetaldehyde	6×10^{-11}	nd	nd	6×10^{-11}	1×10^{-10}	nd	nd	1×10^{-10}
Arsenic	nd	9×10^{-8}	6×10^{-9}	9×10^{-8}	nd	2×10^{-7}	4×10^{-9}	2×10^{-7}
Benzene	4×10^{-7}	7×10^{-10}	nd	4×10^{-7}	1×10^{-6}	2×10^{-9}	nd	1×10^{-6}
Benzo(a)pyrene	5×10^{-8}	2×10^{-10}	2×10^{-11}	5×10^{-8}	1×10^{-7}	5×10^{-10}	1×10^{-11}	1×10^{-7}
Bis(2-ethylhexyl)phthalate	7×10^{-9}	2×10^{-10}	2×10^{-11}	8×10^{-9}	2×10^{-8}	6×10^{-10}	1×10^{-11}	2×10^{-8}
Carcinogenic PAHs	5×10^{-7}	4×10^{-9}	3×10^{-11}	5×10^{-7}	1×10^{-6}	1×10^{-8}	2×10^{-11}	1×10^{-6}
Total PCBs	nd	6×10^{-11}	2×10^{-9}	2×10^{-9}	nd	1×10^{-10}	1×10^{-9}	2×10^{-9}

Note – Total cancer risks are calculated as the chance that an individual's cancer risk would increase based on a particular exposure. For example, a risk of 1×10^{-6} is equal to 1 in 1,000,000 and a risk of 1×10^{-11} is equal to 1 in 100,000,000,000. According to EPA guidance, unacceptable cancer risks are those where an individual's excess cancer risk would be increased by more than 1 in 1,000,000, or 1×10^{-6}.

nd – no data available for either the exposure concentration or for the toxicity of the contaminant

Table 4. Summary of non-cancer hazard quotients associated with playing on synthetic turf fields

Chemical	Non-Cancer HQ							
	Child				Teenager			
	Inhalation	Dermal Adherence	Incidental Ingestion	Total	Inhalation	Dermal Adherence	Incidental Ingestion	Total
Acetaldehyde	0.06	nd	nd	0.06	0.07	nd	nd	0.07
Arsenic	nd	0.005	0.0003	0.05	nd	0.005	0.0001	0.005
Bis(2-ethylhexyl)phthalate	nd	0.00002	0.000002	0.00002	nd	0.00002	0.0000005	0.00002
Benzene	0.006	0.00007	nd	0.006	0.006	0.00007	nd	0.006
Methyl isobutyl ketone	0.0006	nd	nd	0.0006	0.0006	nd	nd	0.0006
Toluene	0.002	0.0002	nd	0.002	0.002	0.0002	nd	0.003
Total PCBs	nd	0.00004	0.001	0.001	nd	0.00004	0.0004	0.0004
Xylene	0.05	nd	nd	0.05	0.05	nd	nd	0.05
Zinc	nd	0.0007	0.0008	0.002	nd	0.0007	0.0003	0.001

Note – Non-cancer risk estimates are calculated as a hazard quotient, with any value greater than 1 considered unacceptable by EPA.
nd – no data available for either the exposure concentration or for the toxicity of the contaminant

The results of this initial evaluation of sport play on synthetic turf fields are consistent with the findings of the other human health risk assessments evaluating the risks from using tire crumb in recreational settings. Despite the use of a highly conservative exposure model (assuming that children and teenagers playing on a sport team will use the turf fields 5 times a week for either 3 or 7 years), cancer risks resulting from dermal contact and through incidental ingestion of tire crumb were all several orders of magnitudes below the EPA risk threshold level of 1 in 1,000,000 and non-cancer risks were all less that 1.0. Risks from the inhalation pathway are all well below the risk threshold for the child sport play scenario and also for the teenage sport play scenario for all chemicals except benzene and carcinogenic PAHs. For these 2 chemicals the risk estimate is at the risk threshold. It should be noted that the inhalation scenario used concentrations of VOCs found in facilities rather than in an open air environment. Using the indoor air value overestimates the likely risks associated with inhalation of VOCs in outdoor environments. The inhalation exposure scenario also assumed that VOC concentration throughout the exposure time remained at steady state to VOC concentrations reported for newly installed indoor turf fields. Moretto (2007) found that the total VOC concentration released from synthetic turf fields decreased over 70% after the first 28 days following installation. Reductions of this magnitude would result in inhalation risks to teenagers to below the threshold criterion of 1 in 1,000,000.

Total risks, that is risks summed across all exposure pathways, exceeds the 1 in 1,000,000 threshold criterion due to the assumption use of indoor-measured VOC data for the inhalation exposure route.

Overall, the balance of the studies reviewed indicate that human health risks from playing on synthetic turf fields is minimal, even though low concentrations of some chemicals have been demonstrated to leach from the tire crumb, or volatilize as vapor. A conservative sport play scenario developed to better describe turf filed use on Bainbridge Island is consistent with the findings reported in the other published studies.

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